

ME 4182
MECHANICAL DESIGN ENGINEERING

NASA/UNIVERSITY
ADVANCED DESIGN PROGRAM

MICRO CORING APPARATUS
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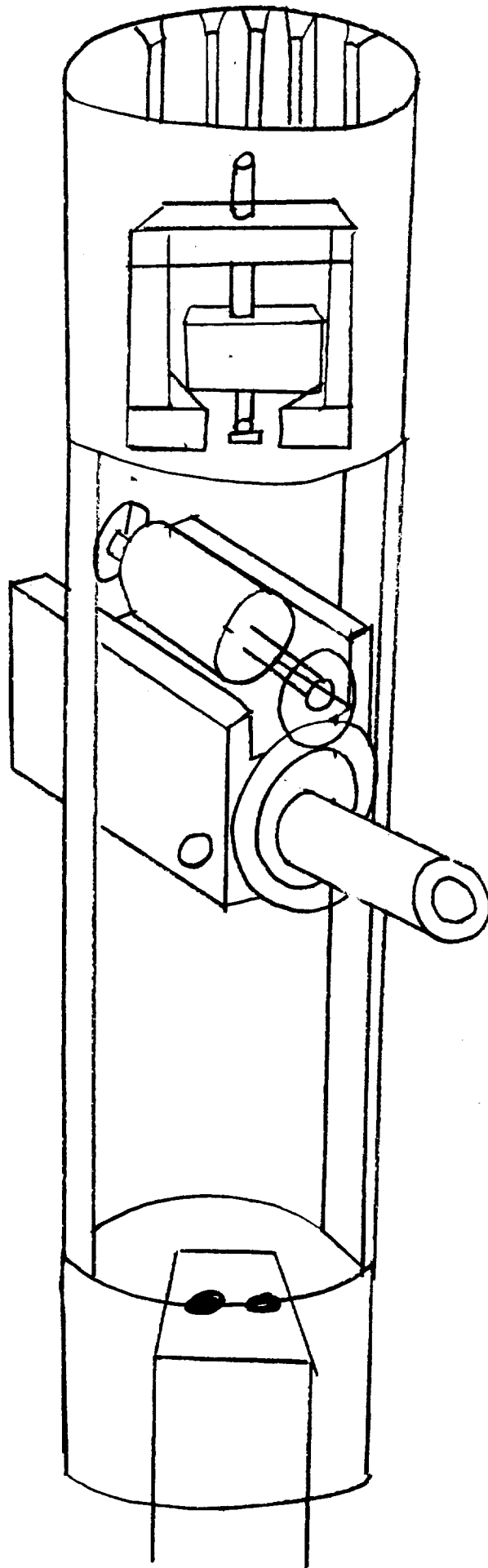


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1.0 Problem Statement

The assignment is to design a micro coring apparatus for lunar exploration applications, that is compatible with the other components of the Walking Mobile Platform.

1.1 Background

The primary purpose of core sampling is to gain an understanding of the geological composition and properties of the prescribed environment. This procedure has been used extensively for Earth studies and in limited applications during lunar explorations.

1.2 Performance Objectives

Several design and performance objectives have been specified to obtain a pristine core sample. They are as follows:

- o The radial core sample is to be approximately 5mm x 25mm long.
- o The core sample must be able to be obtained near the bottom of a 100mm diameter hole that is up to 50m deep.
- o The exact position of the retrieved sample is to be known.
- o The core sample apparatus and lubricants must only minimally affect the physical properties of the sample.
- o The apparatus must be able to protect the core sample from damage and contamination during its transport to the lunar analysis laboratory, where the core drill bit will be replaced.
- o The apparatus must be lightweight, yet durable enough for use in the lunar environment.
- o It must be able to communicate/interface with other mechanisms and components of the Walking Lunar Platform.
- o All power sources and microprocessor controls are to be self contained and recharged at the lunar analysis laboratory.

1.3 Constraints

The lunar environment and the other components of the Mobile Walking Platform greatly add to the obvious design limitations as specified below:

- o The hole diameter is 100mm with potential longitudinal deviations.
- o The overall height of the apparatus is limited to two meters and its diameter must be less than 100mm accounting for clearance.
- o The power source(s) must provide enough energy to accomplish all tasks for retrieval of one core sample.
- o Cooling mechanisms by use of fluids can not be used.
- o The pristine sample must be retrieved in a reasonable period of time.
- o Transport cost rises proportionately as the apparatuses weight increases, at roughly twenty-five thousand dollars per pound.

DESCRIPTION

2.0 LUNACORE A

The LUNACORE A device is a cylindrically shaped, self powered radial core drilling apparatus that can retrieve a pristine micro-core sample in a lunar environment. Its overall dimensions and estimated gross weight values are as listed below:

Height: 2 m

Outside
Diameter: 70 millimeters

Mass: 21 KG

Weight: 200 Newtons (on earth)

34 Newtons (moon equivalent)

The major structural componenets of LUNACORE A are made out of T6061-T6 aluminum alloy, which is a high performance material used commonly in the aerospace industry.

The LUNACORE A device was designed to operate in a pre-drilled 100 mm diameter hole that is up to 50m in depth. It will be placed to the desired depth in the hole by a variable length rod assembly which will be part of the Lunar Drilling Implement, a sub-system of the Mobile Walking Platform.

When the LUNACORE A device is installed to the desired depth, which will be pre-determined by Earth based scientists, it will secure itself in the hole by means of a pair of pad stabilizers, that will engage at different instances. After the upper pad is secured, the platform where the core drill mechanism is located will rotate and orient the core drill bit armature in the precise direction by control of the on board microprocessor. At this time, the lower pad stabilizer will secure itself and the Mobile Walking Platform is free to detach itself from the self-supporting LUNACORE A device. The device is powered by a regulated sealed nickel-cadmium battery modular pack that produces up to twenty-four volts for a duration of five hours.

The core retrieval process is a three step operation. First, a conventional diamond core drill bit, that will not use any cooling fluids, will be used to remove an unpure and slightly larger than desired core sample. After this sample is extracted from the wall, the core drill will rotate to the vertical position and the cylindrical core will be extruded from the core drill bit by a pair of power screw type mechanisms. Next, a fast fracture cutting process will expose five undisturbed or pristine type surfaces on the post-fractured block shaped (5 x 5 x 25 mm : length x width x height) core. The core will then be stowed in a contamination prevention chamber until it is removed at the lunar geology laboratory.

When the core retrieval process is completed, the Mobile Walking Platform is signaled to re-attach itself (if necessary) to the LUNACORE A device, then both pad stabilizers will retract, and the device can be removed from the hole.

The micro-core drilling and fracturing process is estimated to take approximately three hours based on the core drill propagation rate of .250 millimeters per minute. Due to the two hour total coring drilling time, the anticipated wear to the core bit, weight constraints and economic factors, a single core can only be retrieved before the LUNACORE A device will need to have its' core drill bit replaced and its' power module recharged. In addition to this retrofit operation, routine maintenance (i.e., dust particle removal, apparatus decontamination and system performance check), will be performed at the lunar geology laboratory once the micro-core sample is removed from its' contamination prevention chamber.

3.1 POWER MODULE

The power module is an independent unit which supplies electricity to all of LUNACORE A's subsystems. The unit consists of a module cup, two rechargeable batteries, insulation, a wiring harness for charging and discharging, and a recharging connector. When LUNACORE A is sent to the analysis station, the power module will be removed and placed in a recharging stand where it will be restored to full capacity for the next drilling operation.

The rechargeable battery is a sealed nickel cadmium modular pack capable of supplying 24 volts of electricity for up to five hours without recharging. The module cup is a high strength casing, containing the battery and insulation and covered with a reflective coating to minimize heat conduction through the outer wall of the cup. Insulation is placed around the battery and wiring to maintain the desired internal temperature of 60 degrees F \pm 30 degrees during operation. The recharging connector is located at the bottom of the power module.

3.1.1 Battery Selection Criteria

Rechargeable batteries are divided into three types: lead-acid batteries, nickel-cadmium batteries, and silver-zinc batteries. Lead-acid batteries are commonly used in automobiles and heavy equipment. Nickel-cadmium batteries are used mainly in electronics applications. Silver-zinc batteries are used for items like cameras, calculators, and quartz watches. Because of size constraints and voltage requirements, nickel-cadmium batteries were chosen for LUNACORE A's design.

The power source for LUNACORE A is the Burgess model CD-205 sealed nickel cadmium modular pack. Its specifications are as follows:

Voltage output	24 volts
Nominal capacitance	1.2 Amp-hr
Ten hour drain rate	0.12 amps
Length	127 mm
Width	51 mm
Height	46 mm
Weight	2.6 lb.
Charging rate for 14-16 hr charge	0.12 amp

Although a single battery pack has sufficient capacity to power all of the device's operations for one drilling cycle, two batteries are incorporated as a fail-safe measure. During normal operation, only one of the two batteries supplies voltage to LUNACORE A. If the microprocessor senses a low voltage condition in this battery, it switches connections to the second battery pack for the remainder of the operation. Although the backup battery adds 2.6 pounds to the weight of LUNACORE A, the ability to finish the job without removing LUNACORE A from the hole and replacing the power module compensates for the weight penalty.

3.1.2 MODULE CUP

The module cup is a cylindrical unit which houses the components of the power module assembly. Like the rest of LUNACORE A, it is constructed from aluminum alloy T6061-T6. Its overall dimensions are as follows:

Height	270 mm
Outside diameter	70 mm
Inside diameter	68 mm
Wall thickness	1 mm

The battery packs are surrounded by the insulation and are securely placed inside the module cup. The outer wall of the cup is coated with Engelhard Liquid Bright Gold to reflect infrared radiation. This product is first applied to a metallic material and then heated to produce a gold metal film. This film drastically reduces the rate of heat transfer. 100 grams of Liquid Bright Gold will cover 40 to 50 square feet of material with a .1 micron thick film coating. It would weigh about 1.512 grams to cover the entire power module unit.

3.1.3 INSULATOR

The molded Min-K type insulation material manufactured by Johns-Manville is placed around the two batteries and the wiring harnesses. This material was chosen because of its low density of eight pounds per cubic foot and its very low thermal conductivity of .34 BTU/hr-ft²-R.

3.1.4 INTERFACING CONNECTIONS AND POWER MODULE HOLDER

The Elwell Parker (EP) connector manufactured by the East Penn Manufacturing Company, Inc. is used to recharge LUNACORE A. This plug is located at the base of the power module and mates to a matching receptacle on the recharging stand. When the power module is placed in the recharging stand, these connectors engage allowing the module to be recharged.

3.2. MICROPROCESSOR CONTROL SYSTEM

The LUNACORE A microprocessor system is responsible executing the program that will control the following functions on the device:

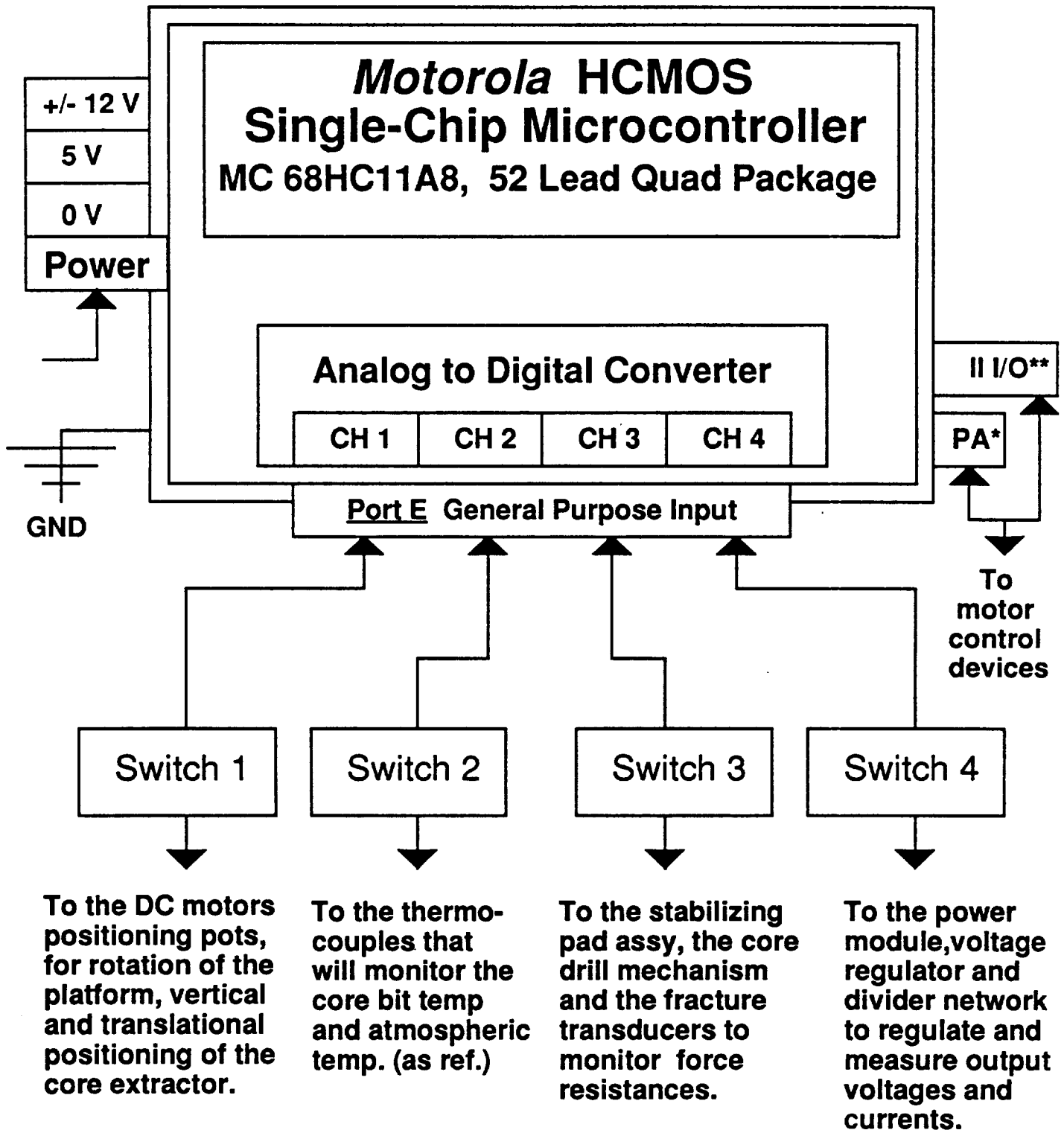
- 1). Controlling all of the DC motors, which includes the core drill motor, the pad stabilization motors, the platform rotation and core drill armature positioning motors.
- 2). Recording the position of the retrieved sample.
- 3). Measuring the pad stabilization locking force.
- 4). Translation of the core drill apparatus and monitoring the bit temperature to prevent a large temperature gradient from building up on the core sample.
- 5). Monitoring the power output of the power module to insure that quiescent voltages and currents are supplied to all electrically powered equipment on the device.
- 6). Activate the solenoid to re-position the core drill motor to engage the gear that will extrude the sample out of the core bit.
- 7). Positioning the sample and controlling the retraction solenoids of the fast fracture mechanism.
- 8). Optically measuring the fractured sample to determine its acceptability.
- 9). Operating the Radio Frequency (RF) communication system with the Walking Mobile Platform.

3.2.1 MICROPROCESSOR SELECTION

The Microprocessor system will utilize a Motorola HCMOS Single-Chip Microcontroller, which is a fifty-two lead quad packaged device. The microprocessor chip will be surface mounted to a small printed circuit expander board allowing it to be connected to the desired components of LUNACORE A. The program to control all the processes of the LUNACORE A device is to be contracted out to an assembly language programmer, who will generate a PROGRM (positive logic sense for address and data), which will then be submitted to the Motorola Company for pattern generation.

As conceptualized, the operation of the control functions occur primarily through PORT E of the chip since the signals will be channeled through an internal analog to digital (A/D) convertor before being processed, See Figure 3.2.1a. This on-board A/D convertor enables us to use dip switches to manage the influx of data over the four port lines. Other ports that will assist in the data collection and control functions of the microcontroller are the parallel input/output and pulse accumulator ports. The pulse accumulator will read the incoming signal from the photo-diodes on the core drill motor to determine and regulate its' RPM's (revolutions per minute).

LUNACORE A Wiring - Microprocessor Diagram



* Pulse Accumulator

FIG 3.1.1a 13

3.2.2 VOLTAGE DIVIDER/REGULATOR CIRCUIT

The voltage monitoring operation by the microprocessor will be extremely important to the overall performance of the LUNACORE A device, since at least five different quiescent voltage values must be maintained. The quiescent voltage source will limit the deviation between the desired platform and core drill armature's positions. In addition, it will insure that the core drill motor maintains a constant RPM, thus limiting the potential for thermal gradients in the heat affected zone of the core sample from occurring.

The desired voltage values for the microcontroller are 0, +/-5, +12 and an anticipated motor voltage may extend into the twenty-four volt range. These different voltage values may be achieved by a voltage divider network, as shown in Figure 3.2.2a. This simplified electrical circuit diagram demonstrates how series resistances will cause a voltage drop to occur by Ohm's Law, $V=iR$, therefore, at each node, a different voltage can be achieved. The voltage regulator is an inductance type circuit where if the voltage varies, the inductance network will either discharge or store energy, therefore the output will remain quiescent.

Voltage Divider Network

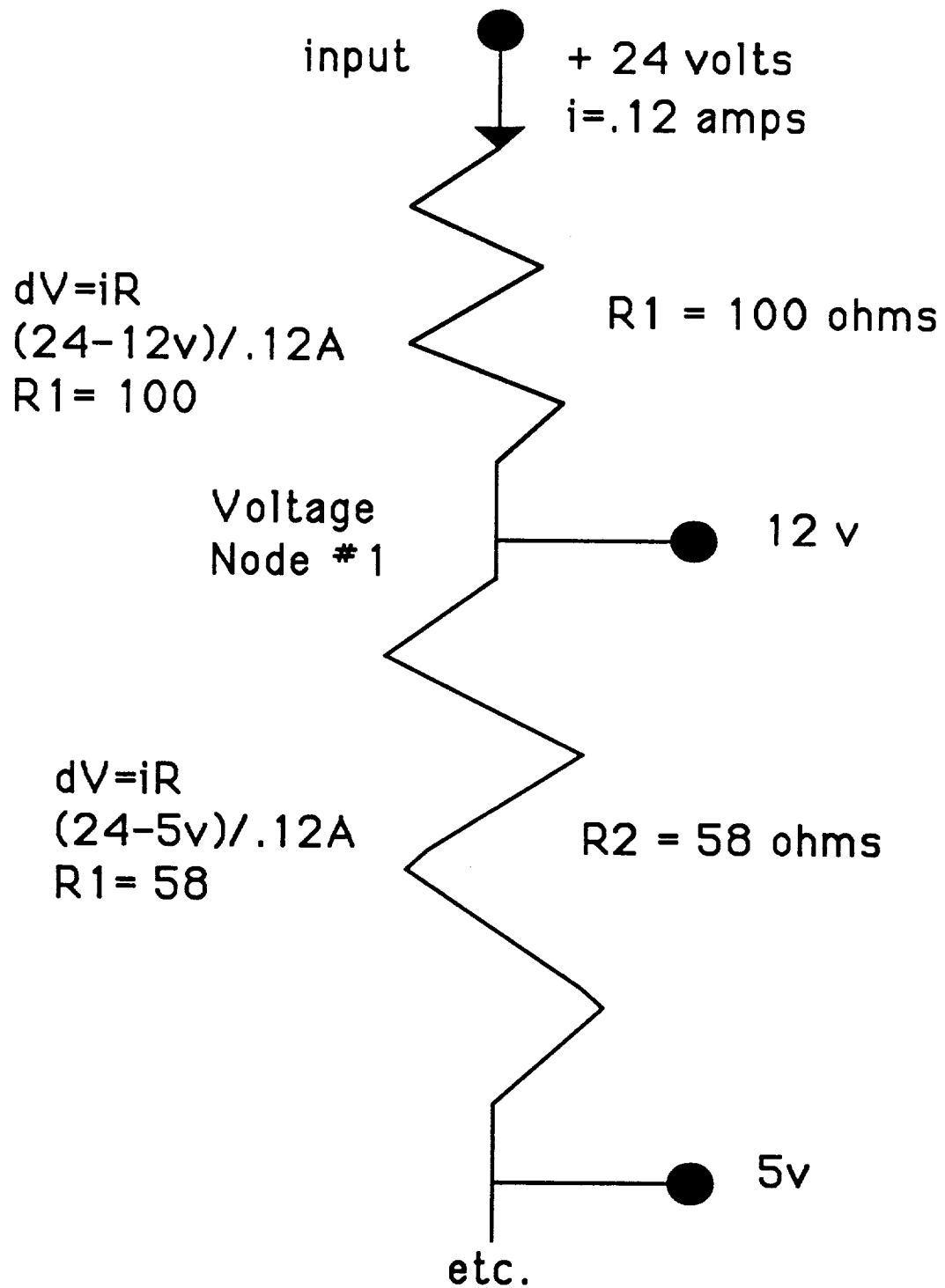


Figure 3.2.2a

3.2.3 SOLENOIDS

As discussed in the fast fracture mechanism, Section 3.5.5, solenoids are incorporated into LUNACORE A's design due to their adaptability to microcontrollers and diversity in their range of motion. Another solenoid will be used to translate the core drill motor, enabling the single motor to accomplish two drive tasks, see Section 3.5, paragraph .

3.2.4 IDENTIFICATION OF ADDITIONAL ELECTRICAL COMPONENTS

To adequately control all the desired functions of the LUNACORE A apparatus, the following devices should be incorporated to interact with the Motorola microcontroller. None of these devices listed below have a part number or particular manufacturer specified since they are common parts and typically have unlimited availability nationwide.

- 1). Semiconducting DIP Switches
- 2). Force Transducers
- 3). Variable Resistors (Pot's)
- 4). Light Emitting Diodes (LED's) and Photo-diodes
- 5). Operational Amplifiers (OP amps)
- 6). Opto-Isolators and Signal Triggering Devices

3.2.5. DIP SWITCHES

DIP switches will be used to control the influx of data to PORT B of the Motorola microcontroller. This is accomplished by the microcontroller digitally signalling the four main DIP switches, to receive information about the performance characteristics of the various sub-systems of the device.

3.2.6. FORCE TRANSDUCERS

Force transducers will be located on the footpads of all the DC motors incorporated into the design to transmit analog force measurement data to the microcontroller. When the desired force is exerted on the mechanism, the power to the motor will be cut off.

3.2.7 VARIABLE RESISTORS

Variable resistors will be utilized to position the platform and core drill apparatus in the desired direction. The advantage of using pots for the positioning application, are as follows:

- 1). The pots can be easily re-calibrated by the microcontroller during the core drilling operation since they are temperature dependent devices.

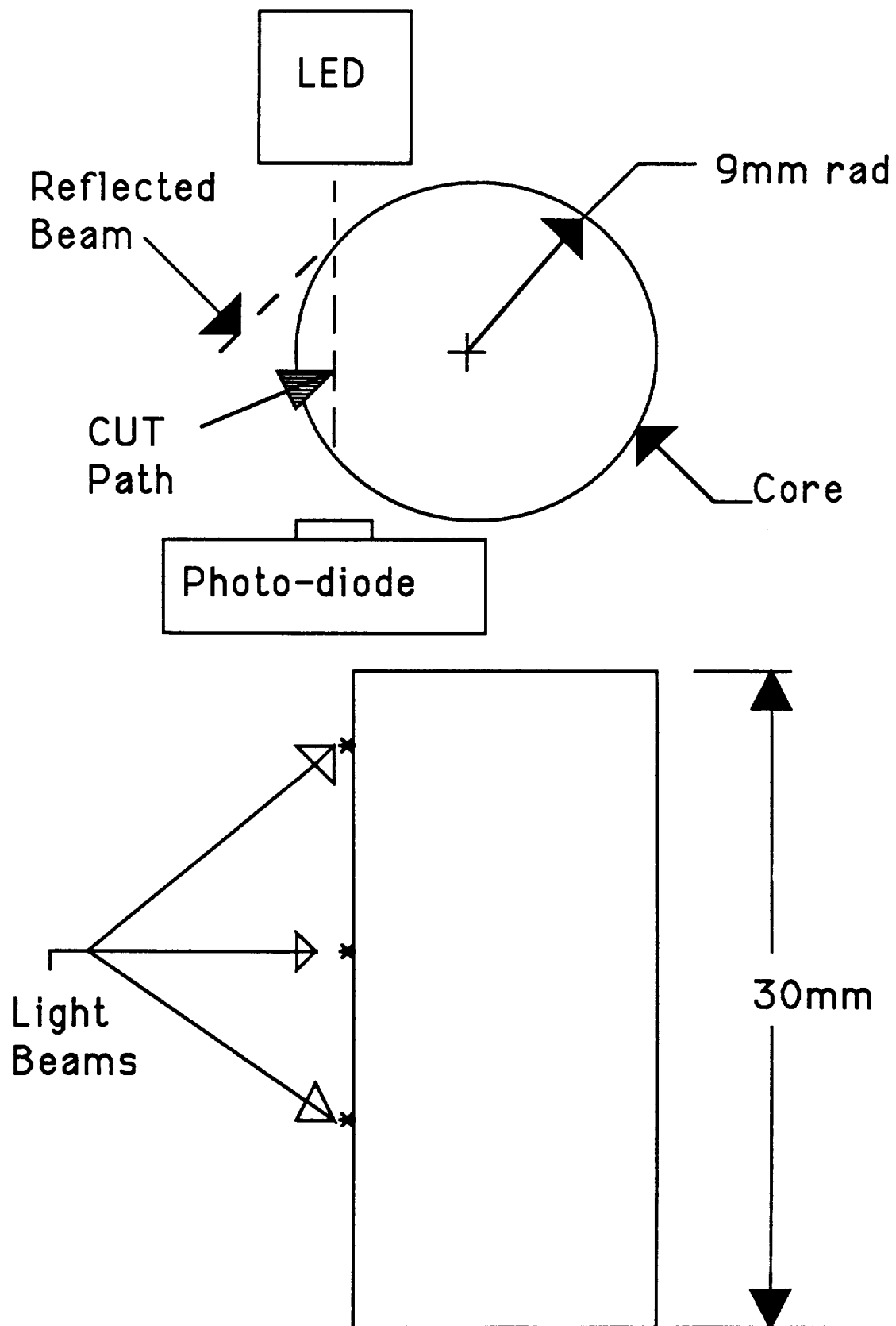
- 2). This constant re-calibration feature minimizes their potential for reporting erroneous location data.
- 3). Variable resistors are low cost devices.
- 4). Interface with microcontroller devices.

3.2.8 LIGHT EMITTING DIODES AND PHOTO-DIODES

LED's and Photo-diodes are light emitting devices that act together to transmit data in the form of pulses. These devices are relatively inexpensive and highly reliable. The LED/Photo-diode pair will be used to determine the motor speed by the light beam emitted from the LED being passed through a slitted shaft on the motor. The signal is collected by the photo-diode. The photo-diode transforms the light signal into a pulse signal that will be interpreted by the Motorola microcontroller.

In a similar manner, the use of a LED and Photodiode setup is desired to optically measure the fractured surface of the core sample. This measurement will be used to determine if the fractured core sample split in a way that will cause it to be unacceptable for laboratory testing or analysis, See Figure 3.2.8a. Optical Measuring System.

Optical Measuring System



3.2.9 OPERATIONAL AMPLIFIERS

Operational amplifiers will be utilized in LUNACORE A's electrical network to increase the strength of a signal before it is processed by the microcontroller. It is known that op-amps will be required for the temperature measuring thermocouples that are to be incorporated into the design. The thermocouples will measure the core bit temperature, which will be referenced to a distant temperature in the 100 mm hole.

3.2.10 OPTO-ISOLATORS AND TRIGGERS

An opto-isolators and triggering devices will be needed to complete the motor control circuit, enabling the microcontroller to interface with the DC motors and the photo-diodes.

3.3 Pad Stabilization Mechanism

The pad stabilization mechanism is used to brace LUNACORE A in place during its operation. The mechanism prevents vertical, horizontal, or radial motion, thus providing a stable platform for the core removal operation.

Two sets of pad stabilization assemblies were incorporated into the LUNACORE A device. The upper assembly engages first and holds the upper section of LUNACORE A in place while the lower section rotates to the desired orientation for drilling. Then the lower section engages to hold LUNACORE A stationary for the duration of the core retrieval process.

3.3.1 Fixed and Moveable Pad Contour Designs

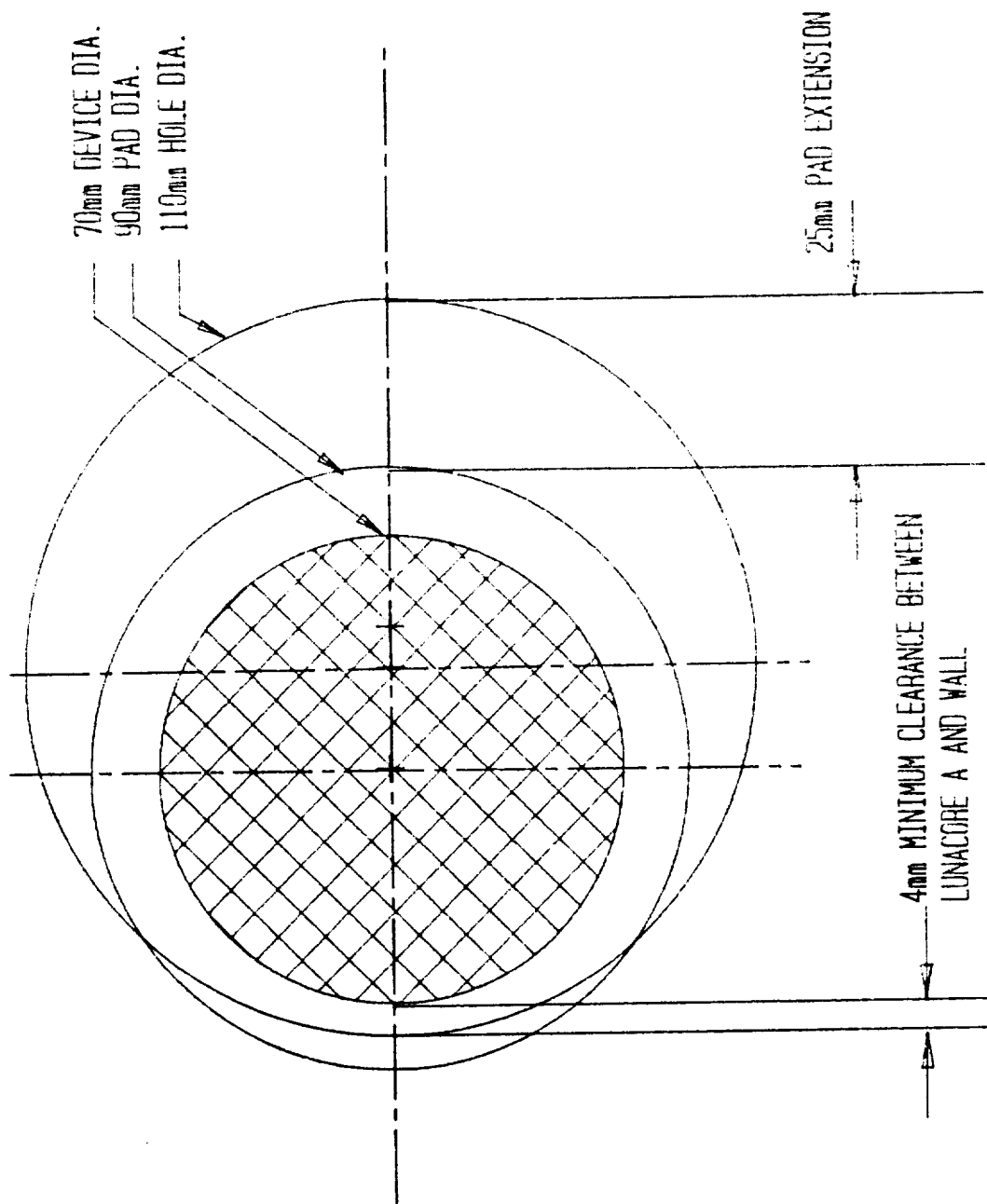
Each pad assembly consists of two fixed pads and one moveable pad. The pads are made from the same type of aluminum alloy as LUNACORE A (T6061-T6). This eliminates any possibility of galvanic effects and assures a strong bond at the joint of the pads to the outer surface of LUNACORE A. A DC electric motor drives an eccentric cam to force the moveable pad outward, and retraction is accomplished by use of a pair of springs in tension. A force transducer is employed at the motor mounting base to determine the amount of locking force exerted on the pad. The pad is held in place by a ratchet type locking mechanism with increments at every ten degrees of rotation. The upper pad assembly is located above the fast fracture section of LUNACORE A. Its orientation is unrelated to the operation of the device. The lower assembly is aligned so that the moveable pad is

positioned 180 degrees opposite to the position of the drill assembly. This assures that the force will be symmetric about the axis of the drill and that the reaction force will be in the same direction as the drill motion.

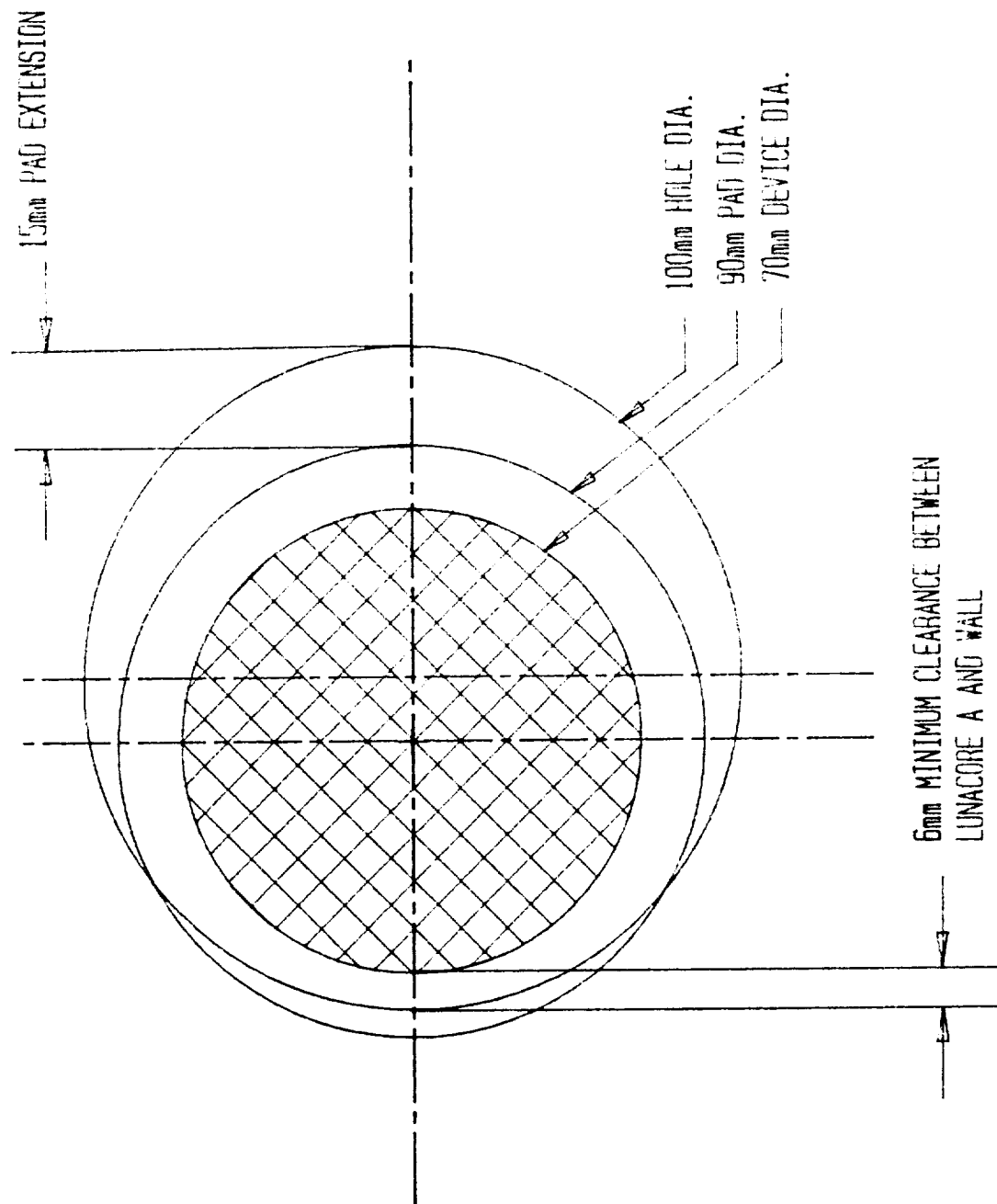
A detailed sketch of the stationary pad design is shown on the next page. The pads are oriented 120 degrees apart from one another. A pad size of 20mm x 20mm was chosen to provide the best contact. The outer edge of the pad is curved with a 50mm radius of curvature to match the wall contour of the hole. A jagged pyramidal surface provides a high coefficient of friction on the wall and concentrates the force at individual points. The moveable pad is 40mm long from the outside edge to the inside surface of the roller follower. The moveable pad projects ten millimeters beyond the outer surface of LUNACORE A when fully retracted. The fixed pads also have a thickness of ten millimeters. The overall diameter is 90mm with the pads in the retracted position, which allows for a five millimeter clearance during the insertion process. Also, the diameter is large enough to prevent unnecessary angular deflection of the drill apparatus during the stabilization process.

Geometric calculations show a nominal travel of 15mm for the moveable pad with a worst case situation (110mm hole diameter at pad location) requiring 25mm of travel. Nominal maximum offset of LUNACORE A (both pads aligned) is 10mm with a worst case situation of 16mm. Usual values would be lower than these figures because the deflection caused by the upper and lower pad mechanisms will tend to cancel. The calculations also show that the lower end of LUNACORE A will not deflect into the side of the hole unless the lower pad is mounted more than 17.5 meters above

OFFSET FOR 110mm HOLE DIA.



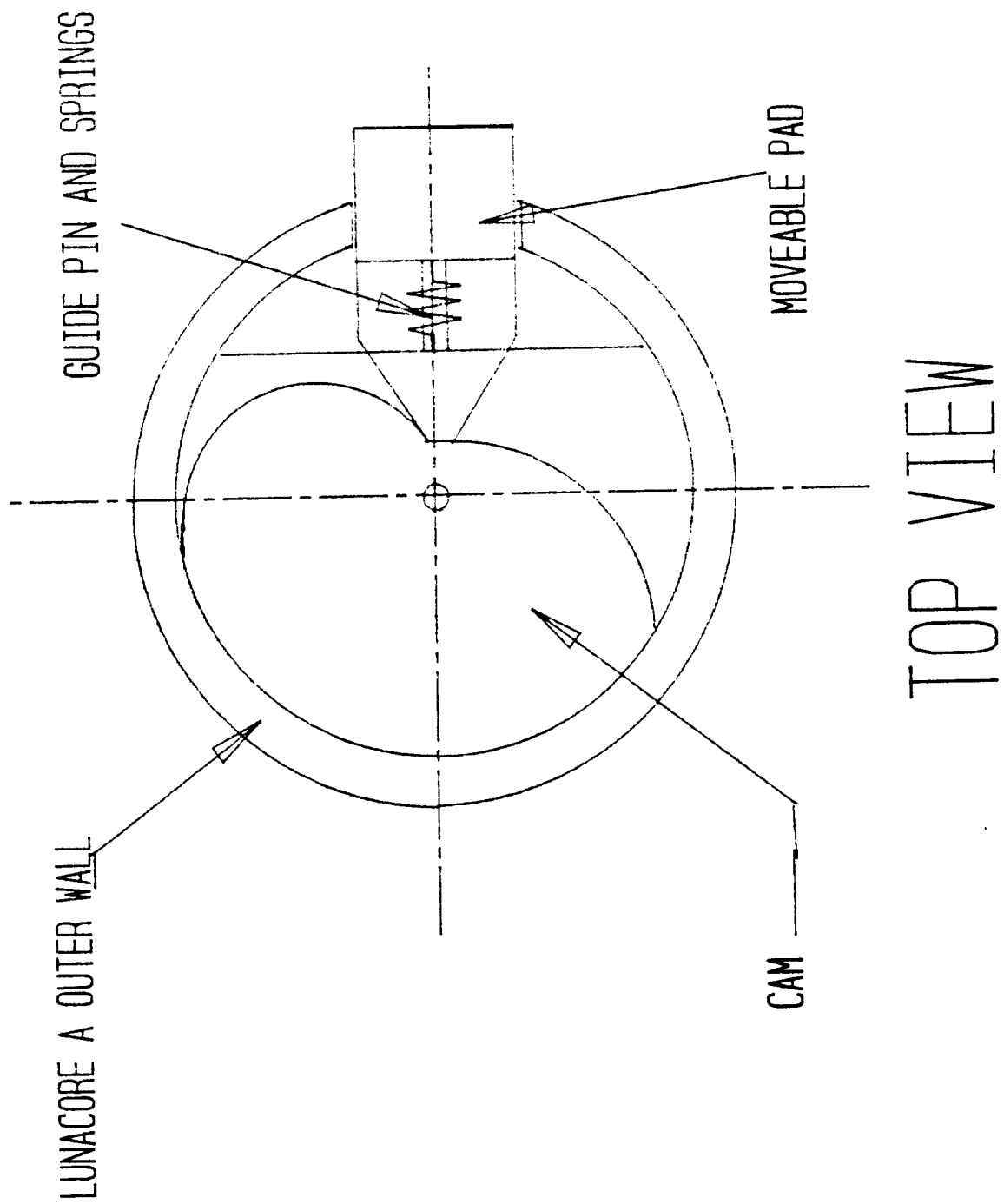
OFFSET FOR 100mm HOLE DIA.



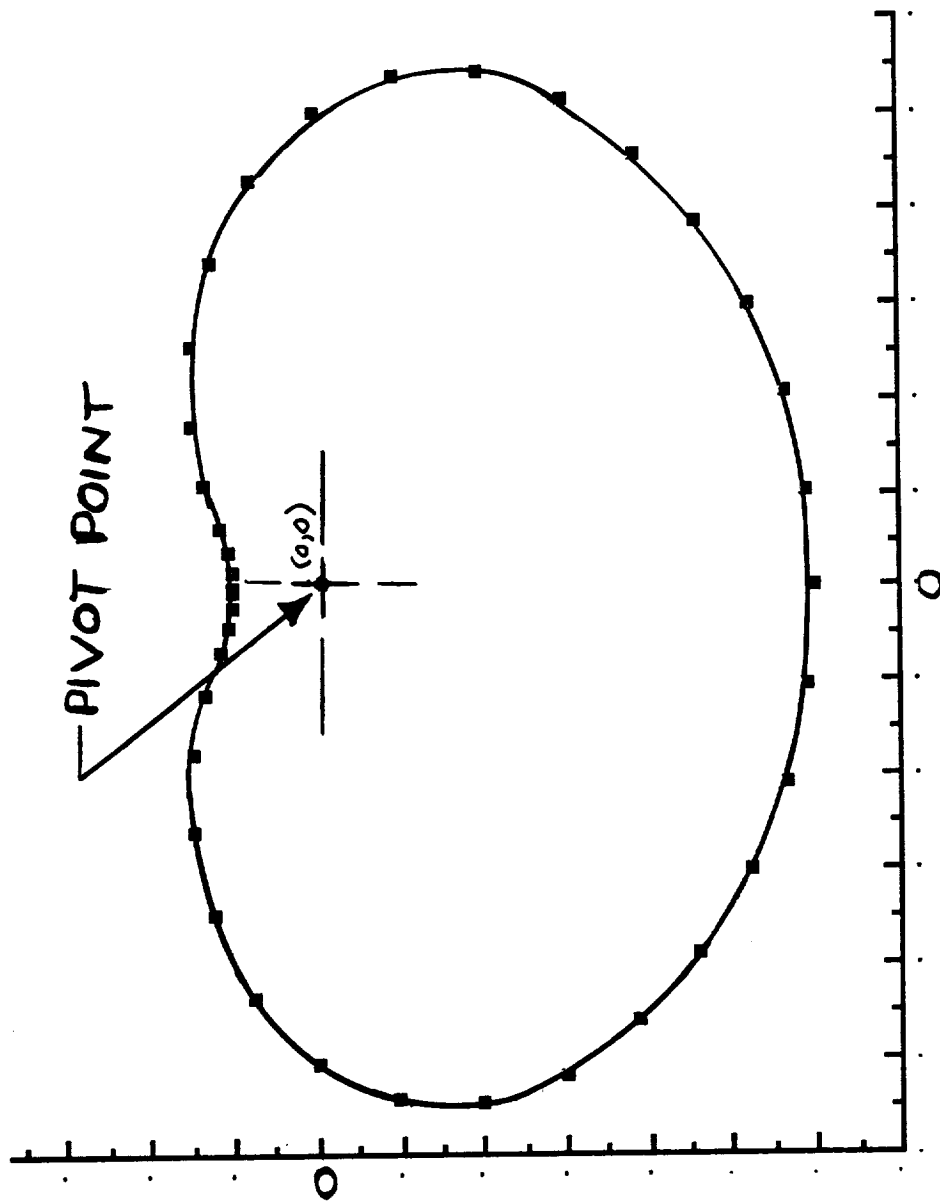
the base of the device. Since our device is constrained to a maximum height of two meters, this will not be a concern. (A summary of these calculations is included in the force analysis section.)

3.3.2 Cam Profile and Retraction Mechanism

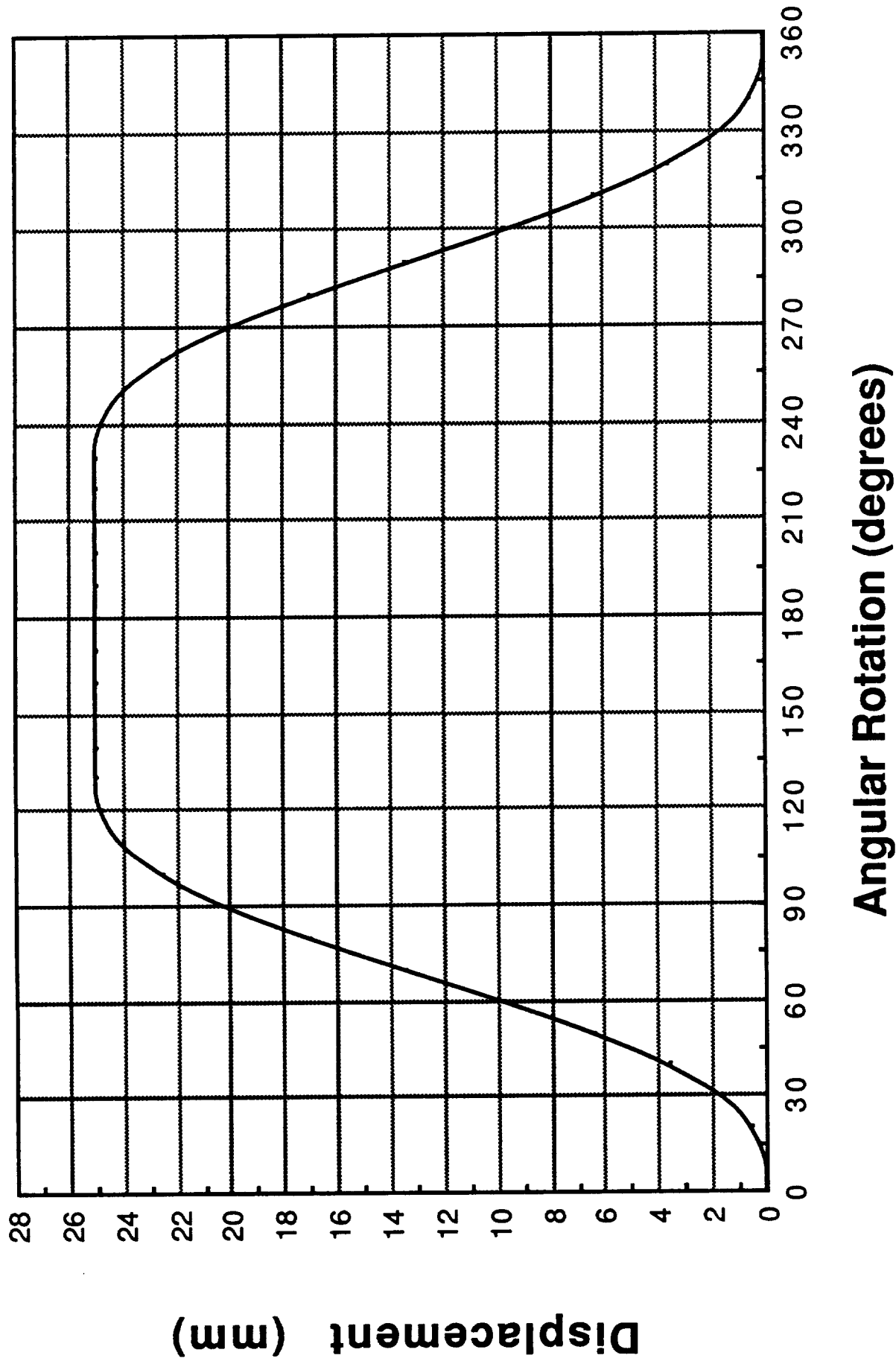
The moveable pad's motion is constrained by a slip fit channel. The cam forces the pad outward until the desired amount of locking force is achieved. The cam was designed with a 5mm base circle and maximum lift is 25mm. Full-rise and full-return cycloidal motion is employed. Cycloidal motion is used because it provides zero acceleration at the boundaries. The rise and return angles are both 135 degrees with a dwell angle of 90 degrees. The cam is locked in place by the aforementioned ratchet mechanism and is released by LUNACORE A's on board microcontroller. Retaining springs are used to retract the pad after the locking mechanism is released. They are helical compression springs with a spring constant of 17.785 lbs-in each. This produces a retracting force of 35 pounds when the springs are fully extended.

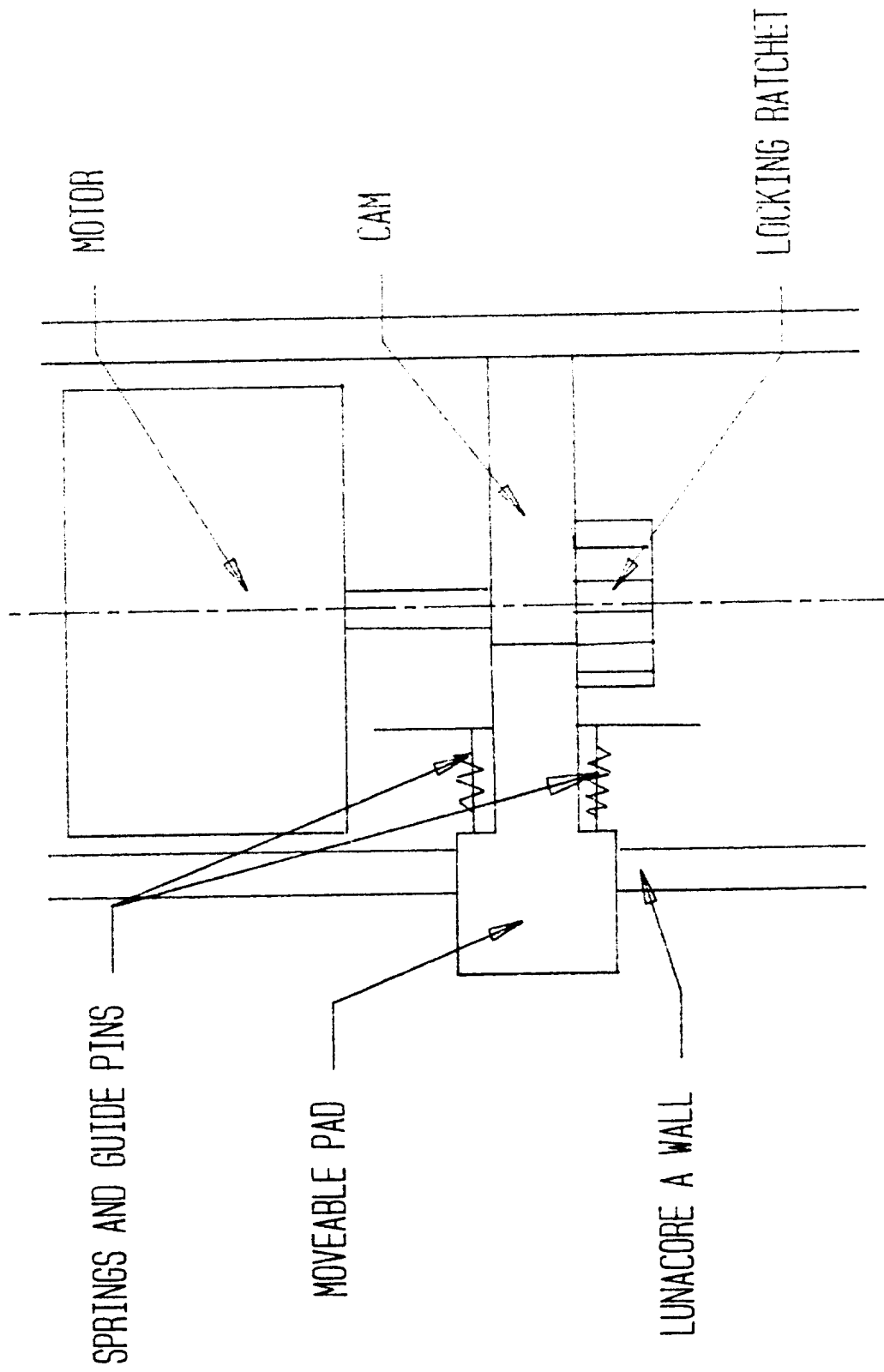


CAM PROFILE

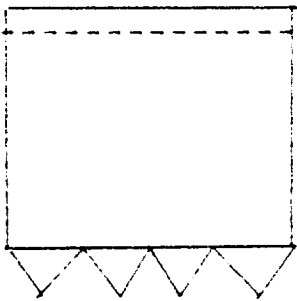
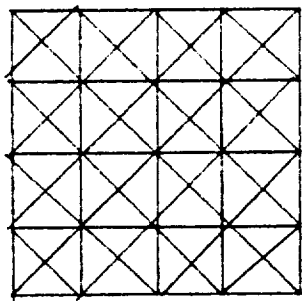


Cam Displacement Diagram





SIDE VIEW



STATIONARY PAD CONFIGURATION

3.3.3 Motor Selection Criteria

A DC motor with the following characteristics is to be employed in the design:

- *Provides 340 in-lbs torque either directly or through a gear train.
- *Can be controlled by the Motorola HCMOS controller.
- *Operates at voltages that do not exceed 24 volts.

The motor will be mounted vertically above the cam for the upper pad assembly. The lower pad assembly is inverted so that the motor is beneath the cam and the ratchet mechanism is above the cam. This configuration allows the pads to be placed closer to the drilling mechanism than would otherwise be possible.

3.3.4 CALCULATIONS AND FORCE ANALYSIS

The geometric construction on the next page was used to determine the amount of offset of LUNACORE A during the drilling operation. As stated before, this construction showed that the maximum amount of travel for the pad was 25mm similar triangles showed that the maximum height for the lower pad was 7 meters.

The page after the geometric constructions shows the cam profile and cam displacement diagram. The cam was generated assuming full-rise and full-return cycloidal motion. The equations for this motion are

$$y = L(\theta/B - 1/(2\pi) \sin(2\pi\theta/B)) \text{ for the rise and}$$

$$y = L(1 - \theta/B + 1/(2\pi) \sin(2\pi\theta/B)) \text{ for the return,}$$

where

$$y = \text{amount of lift of the cam at a value of } \theta,$$

L = maximum lift of the cam, 25mm,

θ = theta = angle into the rise or return motion,

B = duration of rise or return, 135 degrees,

π = pi = 3.1415629,

and the argument of the sine function is assumed to be in radians.

The calculation of the spring constant resulted from the desired 35 pounds of force at maximum extension. The maximum extension of the spring is 25mm or .984 in. Therefore, the desired k is $F/X = 35/.984 = 35.57$ lb/in. for both springs. The value for one spring is then half this value or 17.785 lb/in.

In calculating the motor torque, it was determined that 250 pounds of force should be sufficient to lock the pad in place. The motor also must account for the force of the retaining springs so the total pad extension force is 285 lbs. This force acts at a maximum distance of 30mm or 1.18 inches. Thus the required torque is 285×1.18 or 337 lbs.-in.

3.3.5 RECOMMENDATION

The eccentric cam pad extension method was chosen for several reasons. Foremost, it was best able to accommodate the space limitations of LUNACORE A. It is also a simple and reliable design with comparatively few moving parts. Furthermore, the cam will not chip, as a gear driven mechanism might.

Several other ideas were considered and rejected as a means of stabilizing LUNACORE A. One of these was a motor driven worm gearset which would push the pads out. This was rejected because of the difficulty in locking the device using the drive method

considered. Another idea was an electromagnet which would force the pads out with springs to retract the pads. This idea was rejected because of the energy required to power the electromagnet. Another idea was an inertial system which would force the pads out using a rapid upward jerk. This idea was rejected because it would fail if the side of the hole was irregular and because there was no way to orient LUNACORE A as the pads were being positioned. Finally, a solenoid was considered as a means of extending and retracting the pads. This idea was rejected because of the power consumption and because of the inability of the solenoid to produce enough force to seat the pad properly.

3.4. Core Drill

3.4.1 Heat Transfer Analysis

The analysis of the temperature gradient through the sacrificial portion of the cylinder must be done in order to determine the outer radius needed to keep the inner pristine sample from experiencing a temperature difference of greater than five degrees Kelvin. Geologists prefer a small temperature variation through the sample so they may more accurately determine the age and physical make-up of the rock.

3.4.2 Material Removal Rate

The material removal rate depends only on the cross sectional area of cutting and the feed rate. The feed rate varies with change in power. In a 1972 NASA study on Lunar Drilling, scientists studied the temperature increase, power increase and other characteristics involved with dry drilling a 2 inch core into basalt. The feed rate they used ranged from 0.25 in/min to 3 in/min. In order to achieve this, they also used a drilling speed of 1000 RPM. The 10 horsepower motor required to drill the hole at this speed is far greater than will fit into the 100 mm diameter hole.

By drilling quickly, the scientists found that the heat generated by the friction became a serious bit life problem. For the micro coring apparatus, the problems are multiplied. Not only

is bit life a problem, but heat transfer that raised the inner core temperature is not acceptable.

The drill bit feed rate and rotation rate can be slowed in order to minimize the increase in temperature on the inner core surface. Slowing the bit down decreases the power needed to rotate the bit. Also, the micro core has a much smaller radius (6mm, calculation explained in Heat Generation). Feed rate and cutting area dictate the the material removal rate.

The micro corer has a material removal rate of 0.5 mm/min. Thus, the coring procedure takes a little over one hour total.

3.4.3 Heat Generation

The motor used to drive the drill into the wall uses a maximum of 8 watts with a torque of 10 oz-in (0.7 N-m) and an angular velocity of 12.57 radians per second. Heat is created by the friction between the drill bit and the material. For the worst possible case, the heat into the core system can be approximated as the energy put into the drill. Since the moon is surrounded by a vacuum, the primary method of cooling is conduction into the drill, moon and core sample.

Fortunately, the cuttings from the drilling carry up to 80 percent of the heat. By quickly removing these cuttings from the drill area, the heat transfer into the core is reduced by over 60 percent. An auger implemented on the outside of the drill carries the hot shavings away from the core.

Assuming one dimensional, steady state, constant property

conductive heat transfer, the required outer radius to avoid a harmful temperature gradient is computed. This radius, 6 mm, is modified for a safety factor and then used to find the material removal characteristics of the bit-rock interface.

3.3.5 MICRO CORING PROCESS

Drive Mechanism for the Core Drill / Extractor

The drive mechanism rotates the drill 180 degrees and translates the core drill bit 38mm. The drill rotation is provided by a small worm gear.

Assumptions:

1. The controller must be able to drive the positioning step motors accurately. This is to provide for a good fast fracture position.
2. Two system measurements must be made and provided to the microprocessor during the drilling. One is the force of the wall on the drive, and the other is a measure of heat created during the drilling process.

3.3.6 REMOVAL, STORAGE, AND INSTALLATION OF BIT

The drill bit has to be removed after each drilling procedure for a couple of valid reasons. One being that the bit is too close its melting temperature. The bit also gets in the way

during removal of the core.

3.3.8 Drill Core Extruder

The drill core extruder extrudes the sample position for impact / fast fracturing. After the drive mechanism moves to its vertical position where the sample touches the upper stabilizer, the extruder keeps the lower support on the sample while the drive mechanism retracts.

3.5 FAST FRACTURE MECHANISM

The fast fracture mechanism is a device which will enable the Lunacore A device to expose five pristine surfaces on the core sample. A conventional fluid cooled diamond tipped core drill is not feasible for this application for two reasons. First, the enormous transportation costs involved with transporting disposable fluids to the lunar surface and second is the fact that a pristine sample could not be achieved if contaminated with the cooling fluid. Additionally, a sample that is obtained by the conventional core drilling method will have a surface affected by the heat transfer between the moon rock and the core drill, classifying the outer surface to be contaminated. To obtain a pristine sample it is necessary to separate the rock which is not affected by the heat transfer from the contaminated rock. It should be noted that this process should not take a long period of time. If the duration of the process is long, the pristine rock could become contaminated by the continuous heat transfer .

The fast fracture mechanism will lower itself down from the top of the LUNACORE A to a predetermined location at which time the heat effected portion of the sample will be fractured away leaving a pristine sample. It should be noted that an assumption has been made. This assumption is that the core sample, retrieved from the diamond tip core drill, has a internal portion which is not affected by the transfer of heat.

3.5.1 THEORY

The core sample will be given a 5 mm initial crack on any plane of the core surface. This induced crack, which is a man made flaw in the core's surface, will be used to initiate a crack propagation throughout the specimen. Thus, it is possible to obtain a pristine surface by removing the contaminated material by means of fast fracture. It should be noted that compressing the crystalline lattice would inhibit the fast fracture from occurring in the region which is compressed. Therefore by putting the desired area in compression and initiating a crack down the plane of the contaminated material, the pristine sample can be salvaged before it's temperature rises above the value specified by geologists.

3.5.2 FRACTURE ANALYSIS

The fracture toughness of the moon rocks is assumed to be approximately the same as rocks of similar geological characteristics here on Earth. By knowing this fracture toughness (K_{Ic}) the value of the stress needed to propagate a fast fracture can be approximated. The value of the force needed is 1995 N. This value is calculated by the following equation:

$$K_{Ic} = \sigma \cdot (\pi \cdot a)^{1/2}, \text{ where } a \text{ is the crack length.}$$

Since, $\text{Sigma} = F/A$ (where F is the force and A is the area), the value of the force can be determined by the geometry of the blade and therefore the initial crack (assumed to be approximately the same size as the blade). Figure 3.5b demonstrates this force analysis. By changing the angle of inclination on the blade, the force needed to propagate the fast fracture can therefore be changed and fast fracture can still occur. Listed below are the values calculated from this analysis:

$\text{Sigma} = 1.6\text{E}-7 \text{ N/m}^2$	$A = .1 \text{ mm}$	$a = 90$
$F_x = 1995 \text{ N}$	$B = 3.992 \text{ mm}$	$b = 88.6$
$F_y = 50 \text{ N}$	$C = 3.993 \text{ mm}$	$c = 1.435$
$F_n = 1995.6 \text{ N}$		

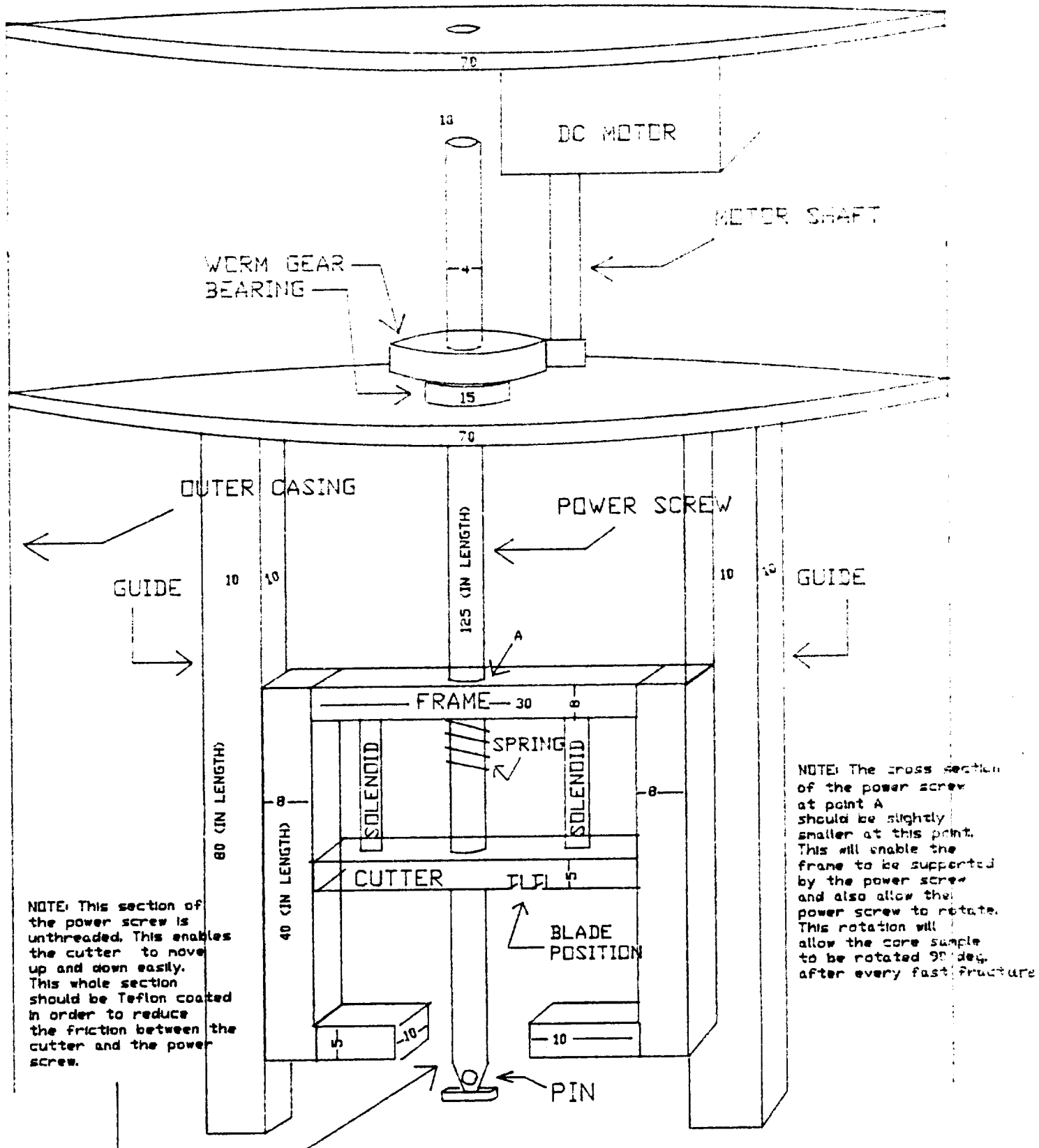
NOTE: The tip of the blade is made of diamond.

The fast fracture mechanism includes the following parts:

- Power screw/DC motor/worm gear/bearings
- Solenoids
- Frame
- Spring
- Cutter/Blade
- Guide

NOTE: Refer to figure 3.5a for a visual aid of the overall fast fracture device.

FIGURE 3.5_a



This device is to be made from T6061-T6 aluminum alloy. Any elements that are not made of this alloy will be specifically mentioned. Listed in Tables 3.5.1 and 3.5.2 are values of constants which were used in the analysis of this device.

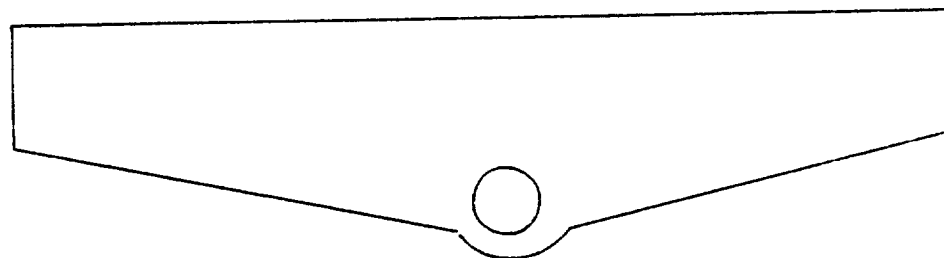
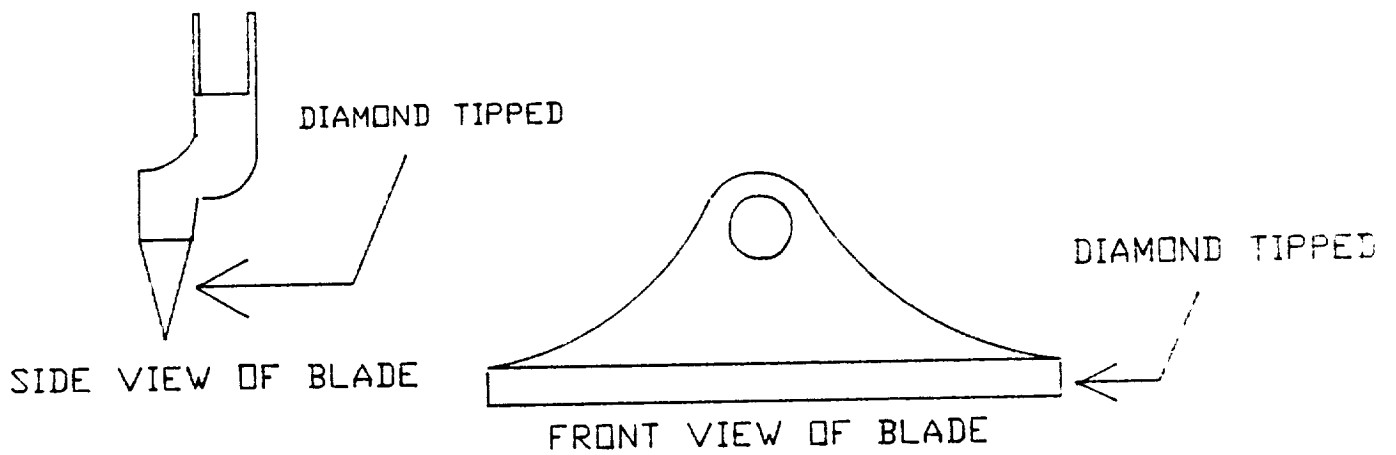
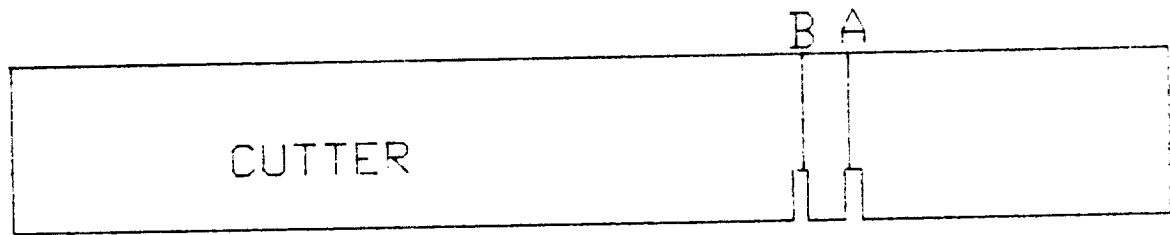
TABLE 3.5.1 - Al *1*

<u>CONSTANT</u>	<u>VALUE</u>	<u>UNITS</u>
Modulus of Elasticity - E	71.0	GPa
Modulus of rigidity - G	26.2	GPa
Unit weight (Al)	26.6	kN/m ³
Density (Al) - p	2790	kg/m ³

TABLE 3.5.2 - Moon rock *2*

<u>CONSTANT</u>	<u>VALUE</u>	<u>UNITS</u>
Modulus of Elasticity - E	100	GN/m ²
Gc	0.04	kJ/m ²
Kc	2.0	MN/m ^{3/2}

FIGURE 3.5c



CROSS SECTION AT A AND B

Force Analysis for Fast Fracture

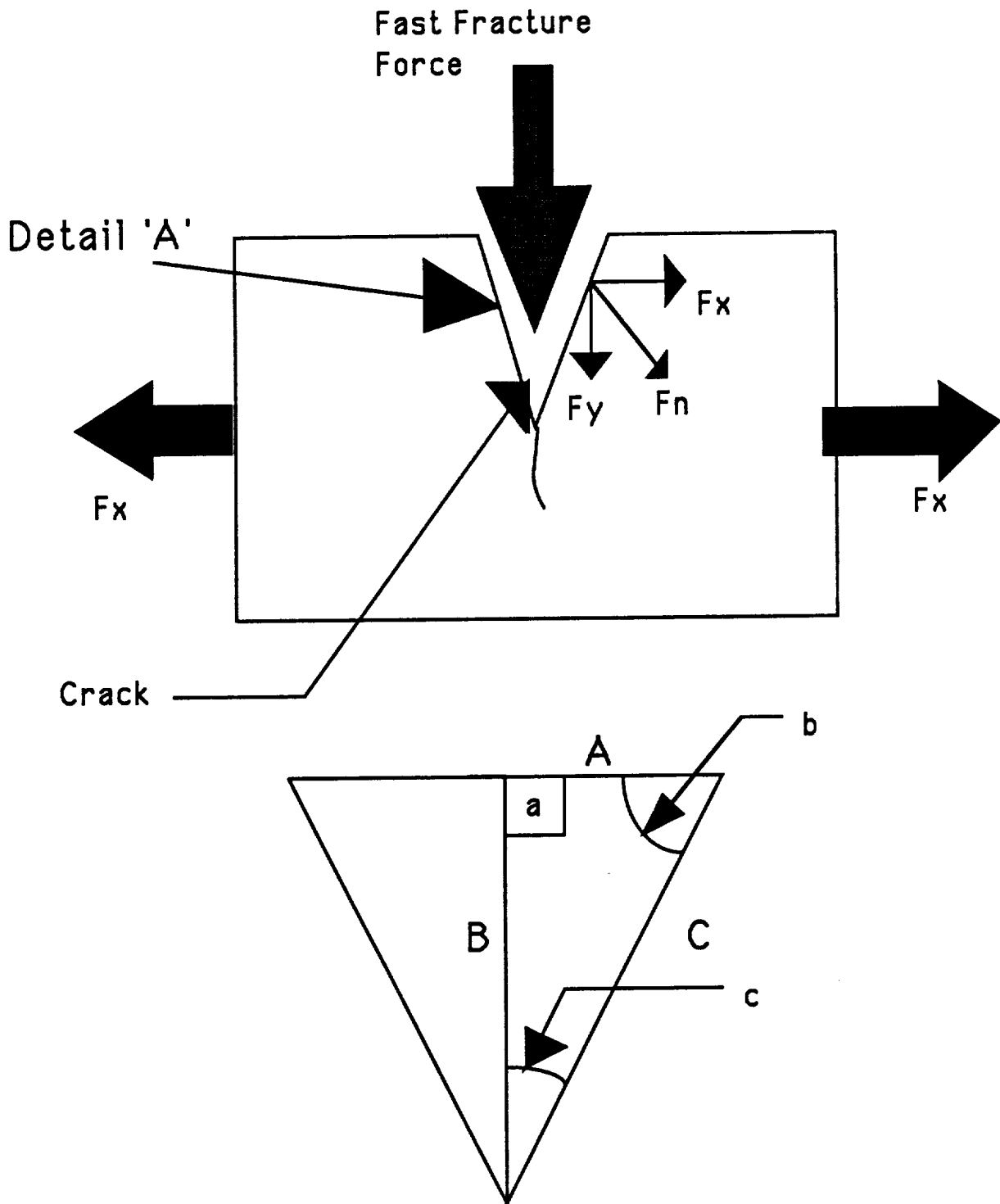


Figure 3.5b

3.5.3 SPRING

The spring is compressed by two 24 V solenoids which are mounted inside the frame. The spring is made of UNS G61500 music wire and has squared ends. The number of active turns (N) is 10 and for squared ends number of total turns (Nt) is 11. The mean spring diameter (D) is 7 mm and the wire diameter is 1 mm. The deflection y needed to obtain a 50 N force is 17.3 mm. The solid length and free length are 11 mm and 27.3 mm respectively. Finally, the spring constant is 2.89 N/mm. Note: All of these values were calculated from the basic equations governing springs. The solenoids will be turned off and the spring will power the cutter which will propagate the crack.

3.5.4 CUTTER

The cutter is 30 mm x 10 mm x 5 mm and has a blade attached to it by pin (see figure 3.5c). This blade is free to rotate and can therefore compensate for any angles which might be present on the top of the core sample caused by shearing the core away from the moon. The blade attached to the cutter will then travel down the shaft and the frame which has tracks on it (similar to railroad tracks) to help guide the cutter. The cutter has grooves in it which enable it to glide up and down the frame. Another advantage with using the track concept over having the cutter slide down the side of the frame is that the surface area of contact between the cutter and the frame is reduced. Thus the

friction between the cutter and the frame is reduced. NOTE: The surface area between all moving part is coated with Teflon to help reduce friction and wear. The blade tip is diamond and the exact specifications have been given in the force analysis. The overall design of the blade needs further conciderations.

3.5.5 SOLENOIDS

The solenoids ratings are as follows:

Rated Voltage = 24 V

Rated Stroke = 30 mm

Rated Attraction Force = 30 N

There is an shortage of data on solenioids which have been rated for use in a vacuum. The ratings above are for an altitude of 2000 m or less. There is a word of caution when basing data on un-related rating scales (such as changes in pressure or no pressure as in a vacuum).

3.5.6 POWER SCREW/DC MOTOR

The fast fracture mechanism will be stored in the top of the LUNACORE A. After a initial sample has been obtained, the core drill will come to a upright locked position. At this time the fast fracture device will be activated. The whole device is brought out of its' storage position via a power screw. This power screw will be powered by a small dc motor. The power screw enables rotary motion to be transmitted into linear motion. The total weight of the parts which will be supported by the power screw can be estimated to be 0.5 N. The power screw has 6 square threads per millimeter, double threads and a major diameter of 4 mm. The pitch is 1/6 mm and the thread depth and width is equal to half the pitch. Various other parameters are needed to obtain the characteristics of the power screw. These are listed below in Table 3.5.3 and the characteristics of the power screw are listed in Table 3.5.4.

TABLE 3.5.3

Mean diameter - d_m	3.167 mm
Minor diameter - d_r	2.333 mm
Lead - l	.333 mm
$u = u_c$ (assumed) *3*	0.08
Collar diameter	15 mm

TABLE 3.5.4

Tr (raising torque)	39.0 N mm
Tl (lowering torque)	33.7 N mm
Efficiency	6.79 %

Note: Further reseach and developement needs to be focused for the determination of a suitable DC motor and worm gear which will create the needed torques above.

3.5.7 FRAME/GUIDE

The frame comprised of five parts which can be seen in figure 3.5a. This figure gives the dimensions of the frame as well as the guide.

There needs to be further research and developement in this area of Lunacore A since this is a totally new concept and has never been tested it is hard to obtain specifics pertaining to a complete design.

Recommendations and Conclusion

The first and foremost problem lies with the rod interface. The interface between the micro-coring device and the rods above needs to be determined before continuing much further.

The pad stabilization mechanism needs a motor to supply a torque of 340 in-lb to the retaining springs. More research needs to be put into finding a motor that can supply the torque and fit in the space restrictions.

Further research and experimentation should be done on a self supporting power module. The idea of implementing a solar outer shell onto the lunar coring apparatus for the purposes of independence from skitter should be a future consideration.

Alternative methods for cooling the bit should be considered. Cooling can be achieved by conducting heat to fins in the 100mm hole. The fins can then radiate heat to the wall of the hole. For high powered drilling procedures, the larger temperature differences can justify extended fins for the purpose of radiative heat transfer.

Other methods of cooling considered in this case were solid state cooling and heat pipes with capillary action. Neither of these methods was needed because of the rapid heat removal due to the removal of the cuttings, but, if the drilling process is sped up, the need for another heat sink may be justified.

The separation of the drilled core from the moon takes far more power than is available for the space requirements. The idea of using a cam to break the core from the moon should be investigated, as should some type of fast fracture technique. Depending on the method of extraction, the integrity of the pristine sample can vary. The sample needs to stay untainted at least until it reaches the lab. Therefore, the sample must be stored in a clean chamber for the trip to the lab.

Time constraints did not permit a full dynamic analysis of the coring drill or drive. It is suggested that the force analysis for both gears and the shafts be fully designed during the next design phase.

The complex control network should progress hand in hand with the mechanical design. One project that needs more research is the communication link between the remote lunar micro coring device and skitter. The ideas and basic outline for future programming have been done, but the network has not been tied together. The final goal for the control system is to achieve a closed loop control system.

The lunar micro-coring apparatus has undergone a rigorous first stage design procedure. The unique fast fracturing idea for preserving geological pristinity appears to be the perfect solution for taking care of the heat affected zone. However, the idea needs more testing to prove its validity and reliability. One of the most challenging problems to this group as well as to a few professors and graduate students is modeling the heat transfer as the drill moves through the moon rock.